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September 2015

Trade Space Analysis: Rotational Analyst Research Project

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Trade Space Analysis: Rotational Analyst Research Project

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ABSTRACT

This is one of two products exploring trade space analysis. This document is a technical report that outlines the assignment approach, TRAC case study, and recommendations for further exploration in trade space analysis application and methodologies. The main recommendations are developing decision support tools such as dashboards built around meta-models, the adaptation of a slightly different set of definitions for capabilities and requirements to open up the aperture to more of the Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities, and Policy (DOTMLPF-P) domains. The product of this research project is a second document, A Descriptive Guide to Trade Space Analysis. The guide asserts there are three primary components that make up trade space analysis: physical characteristics, capability attributes, and applied utility (value or priority). Finding the balance between all three of these components is what drives decision outcomes. It provides a description of several challenges associated with the conduct of trade space analysis and elements that must be contended with throughout the analysis. The guide offers a potential framework with which to build out a capabilities trade space analysis using the Quality Function Deployment model. Its structure facilitates communication, planning, and decision making at a variety of levels throughout the requirement and system development process.

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LIST OF ACRONYMS AND ABBREVIATIONS

AoA	Analysis of Alternatives
BOD	Board of Directors
C-BA	Cost-Benefit Analysis
CDD	Capabilities Development Document
COA	Course of Action
CNA	Capability Needs Analysis
CPR	Capabilities Portfolio Review
DAU	Defense Acquisition University
DCO	Defense Connect Online
DoD	Department of Defense
DoE	Design of Experiments
DOTMLPF-P	Doctrine, Organization, Training, Material, Leadership and Education, Personnel, Facilities, and Policy
ECP	Engineering Change Proposal
FLVN	Fort Leavenworth
GCV	Ground Combat Vehicle
HD	Human Dimension
HSI	Human Systems Integration
ICD	Initial Capabilities Document
IFV	Infantry Fighting Vehicle
LIRA	Long Range Investment Requirements Analysis
JCIDS	Joint Capabilities Integration D System
LRPF	Long Range Precision Fires

MMT	Methods, Models, and Tools
MSA	Milestone A
MSB	Milestone B
MTRY	Monterey
NPS	Naval Postgraduate School
QFD	Quality Function Deployment
OR	Operations Research
OSD CAPE	Office of the Secretary of Defense
PA&E	Program Assessment and Evaluation
POM	Program Objective Memoranda
PM	Program Manager
RFP	Request for Proposal
ROM	Rough Order Magnitude
RSM	Response Surface Method
RSE	Response Surface Equation
SE	Systems Engineering
SME	Subject Matter Expert
TCM	TRADOC Capabilities Manager
TRAC	Training and Doctrine Command Analysis Center
TRADOC	Training and Doctrine Command
TWV	Tactical Wheeled Vehicle
USAF	United States Air Force
USAR	United States Army Reserve
VFT	Value Focused Thinking
WSMR	White Sands Missile Range

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I would like to thank LTC Smith and the team at TRAC-MTRY for making this assignment possible. I would especially like to thank the faculty who took the time to meet with me and the TRAC-MTRY team for providing valuable input and resources for this review. Additionally, I would like to thank the TRAC BOD for the opportunity to see TRAC from another point of view.

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SECTION 1. INTRODUCTION

The objective of this assignment at TRAC-MTRY was to "explore the variety of trade space methodologies used throughout TRAC, explore current methods, models and tools (MMT), and advance suggestions for future MMT or research". As a result of this effort, I hope to be able to provide TRAC with an exploration of trade space analysis that provides some insight into opportunities for further analyses and research, and outline some useful information related to its application for analysts. The intended audiences for this document are those who selected this research topic, the Research Council, and anyone who might be interested in the recommendations for further exploration of trade space analysis MMT.

1.1. PROBLEM STATEMENT

Trade Space Analysis does not dictate methodology or technique, which leaves both an area for continual analysis and potentially a lack of clarity on how to analyze specific trades.

1.2. TASK OVERVIEW

- Conduct a detailed literature review of Trade Space analysis methodologies and applications, of special interest are those methodologies used for exploring trades across DOTMLPF-P.
- Review TRAC application of Trade Space analysis methodologies.
- Document results in a technical report and establish a resource site for TRAC collaboration on Trade Space analysis techniques and lessons learned.

1.3. CONSTRAINTS, LIMITATIONS, & ASSUMPTIONS

Constraints limit the study team's options to conduct the study.

- The project will be completed by 30 April 2015.

Limitations are a study team's inability to investigate issues within the sponsor's bounds.

- The methodologies and techniques considered will be feasible for use within TRAC studies.

Assumptions are study specific statements that are taken as true in the absence of facts.

- The methodologies applied in recent TRAC studies represent the scope of Trade Space Analysis applications.

1.4. REPORT ORGANIZATION

This document is the overview of the task, process and resources used during this project. It has three main sections. This section provides an overview of the trade space analysis topic. The following section covers the applied approach. The final section summarizes the effort and identifies several areas for potential follow on research activities. The product of this research effort is a second document. It is intended to be an analyst guide to trade space analysis principles and basic tenets to consider when conducting trade space analysis.

SECTION 2. APPROACH

The following graphic depicts the project approach. The majority of energy spent focused on the literature review; exploring applications of trade space analysis methodologies and characterizing examples of TRAC trades work. This section summarizes the implementation of the approach.

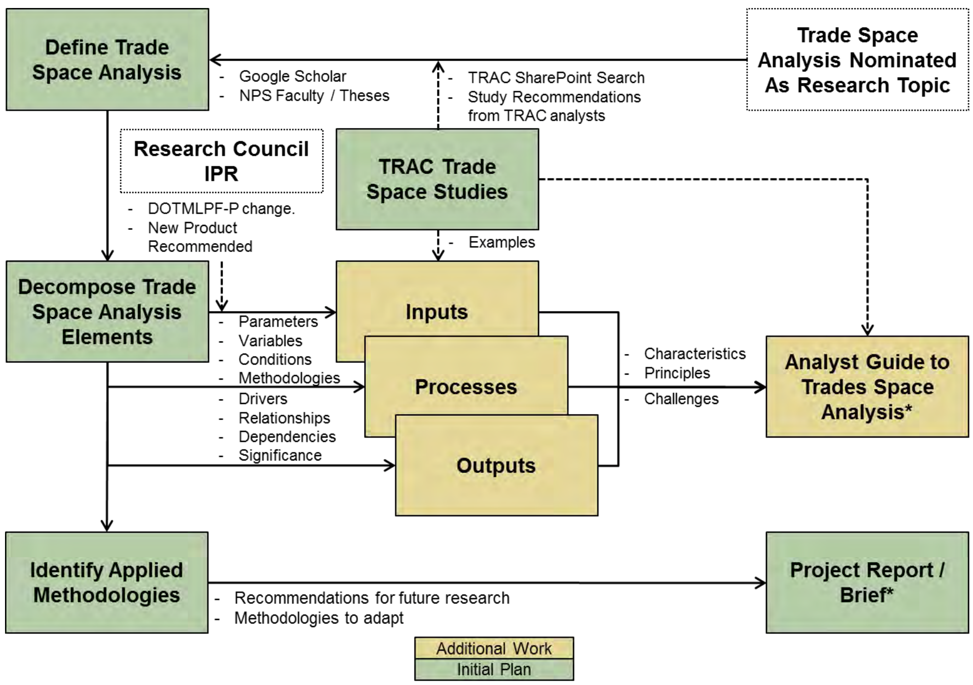

Figure 1: Trade Space Analysis Research Methodology

2.1. COLLABORATION

Numerous types of engagements throughout the project informed the structure and content. I met with NPS faculty of the Operations Research and Systems Engineering departments to discuss general principles and some of the ongoing research related to trade space analysis. I held a DCO session with the TRAC Research Council to check progress and ensure the end product is of the utmost utility to potential readers. During the meeting with the Research Council, we determined that addressing DOT_LPF-P domains in depth here is beyond the scope of this project. I met regularly with the Director of TRAC-MTRY for in-process-review discussions. I reached out to a number of analysts who worked the identified studies for their experience, advice, and to identify any challenges they faced throughout the analysis process.

2.2. RESEARCH

The primary vehicles of the literature review included the NPS library and Google Scholar. Additionally, based on a recommendation presented at the Tufte "Presenting Data and

Information Course", Google Images was an alternative search engine. Interestingly, it yielded a greater number of relevant results than a regular web search. Here are the steps of the Literature Review process that expedited the collection of resources: word search, read abstract and conclusion for relevance and interest, and of those selected review the articles cited in their reference sections. This may be common knowledge, but it was a learning experience for me.

2.3. TRAC CASE STUDY

The table on the following two pages describes some of the studies used to characterize TRAC trade space analysis. I identified these studies through: a universal word search (*trade, tradeoff, trade space, tradespace)* in the TRAC SharePoint projects directory, TRAC analyst recommendations, principle analyst input, and NPS faculty references to work done with TRAC-MTRY.

I established a framework with which to review the studies that would be able to account for the variety of trades analysis that TRAC conducts. The following descriptions of table headings provide that framework:

- Study: Title and time frame.
- Informs: What does the study inform?
  - To include JCIDS Milestone decisions, budget / planning, decision support, etc.
- Trades Objective: What was the goal of the trades analysis; as it related to the decision it informed and / or associated study objectives?
  - To include what initiated the requirement for the trades analysis (as a result of…)
  - Or, what the assessment informed (in order to…)
- Trades Methodology: What were the MMT used to identify, characterize, and / or assess trades?
  - To include metrics and measures.
- Trades Considered: What attributes or characteristics of the problem informed the decision outcome or how well objectives were met?

As a result of the review, I characterized these studies into three general bins based on the types of decisions informed, trades considered, and methodologies applied. The most common TRAC Trade Space Analyses focuses on the 'ilities' provided by materiel solutions. These were capability based assessments (e.g. AoA, requirements analysis) that characterized **system attributes** and performance values – usually tethered to (or informing) the capabilities and associated gaps outlined in requirements documents (e.g. ICD and CDD) as reference points – at various decision points in the acquisition process. These primarily focused on tradeoffs such as cost, schedule, risk, and performance defined in the AoA Study Guidance Template.

Other study types considered as trades analyses were **budget / planning**, and **composition / mix** related analyses. Budget / planning trades depended more heavily on stakeholder value measures. Composition / mix trades commonly used some combination of stakeholder value measures and some tradeoff categories related to cost, schedule, risk, or performance.

Table 1: TRAC Case Studies

	Study	Informs	Trades Objective	Trades Methodology	Trades Considered
1	Joint Light Tactical Vehicle (JLTV) AoA (2011)	MSB	After initial analysis were complete and no alternative met all requirements: Identify cost-informed trades to underpin changes to requirements to meet the cost target for procurement of a new start materiel replacement.	Analysis investigated requirements cost drivers and their effect on performance; A fixed APUC value was applied and sub-thresholds were established. Analysis considered niche requirements performance attributes. * Payload was originally considered; analysis determined it was not a candidate.	Mobility Reliability Fuel Efficiency Transportability * Cost & Affordability
2	GCV AoA (2010)	MSA, Revised RFP	"Inform development of a revised GCV RFP that provides contract requirements to permit vendors to develop offers that meet the Army's intent and cost target."	Identify sub-threshold trades in each capability area that will achieve lower cost point; using qualitative (performance level and operational models) and or quantitative (SME inputs) methods to assess tradeable technology performance. Follow-on gap mitigation assessment determined impact of final trade vehicle design.	Sensors Lethality Force Protection Survivability
3	GCV AoA Parametric Analysis (2012)	MSB Decision, Phase 1	Conduct system-level and force effectiveness analysis of various technologies to determine their impact on infantry fighting vehicle (IFV) performance attributes; inform the CDD requirements.	Used a (Principle Half Factorial) DOE to focus the modeling and analysis efforts to determine significance and interrelationships between technologies; examined high and low performance values for technologies on both the Current IFV platform and Future IFV concept design.	Lethality Survivability Force protection Mobility
	LRPF AoA (2014)	MSA Decision	Design Level Trades: Identify component level trades to select representative technology combinations.*	Identify all technologically feasible combinations and then use Principle component analysis – cluster analysis – to identify select technology combinations (# Per Pod, Warhead Weight, Fuze Type, Guidance, Range) that reflect the design space.	Cost Schedule Risk Range Lethality
4			*System Level Trades: Use representative combination in 'ilities' based operational assessment.	Conduct combat modeling to conduct further system level operational effectiveness analysis understand how technology trades result in attribute trades and highlight those trades.	Lethality Range Sustainability/Survivabilit y Responsiveness
5	BCT Design and Other Force Structure Trades (2014)	Force Design Reduction	Identify the risk associated with a variety of COA that reduce end strength and expand solution space to maintain capability.	A value-based approach dependent on five risk assessments: initial warfighter seminar, tactical, operational, headquarters, and force-level assessments that focuses on the impacts on Army core competencies and ability to achieve concept tenets. Measure: Relative risk of design options' capabilities when conducting missions/tasks and associated DOTMLPF-P implications.	Potential capability trades (dependent on mission task type): Readiness, Lethality, Ability to Detect, Survivability, Sustainment Requirements, and Persistence/Area of Coverage.

	Study	Informs	Trades Objective	Trades Methodology	Trades Considered
6	Bradley Non-IFV C-BA (2012)	Army Systems Acquisition Review Council (ASARC) review in 4QFY12.	Determine the cost-effectiveness of proposed technologies for inclusion in ECP 3: Identify performance, cost, and risk associated with the technologies within each COA to determine the overall risk associated with each COA.	Traced technologies to capabilities (PM Bradley established COAs). Applied attribute weighting provided by TCM ABCT (CPAT priority weights). Used performance based models to provide insights on impacts of changing out technologies (Performance, Sustainment, and Cost). Measure: weighted utility value for performance, cost, and risk measures.	Network Lethality Mobility Protection
7	Abrams C-BA (2011)	ECP decisions after the cancellation of AoA	Determine which technologies should be pursued to enhance the capability of the Abrams within the constraints of the ECP process: "Recommended courses of action (COAs) based on ECP eligibility, performance benefits, operational benefits, and risk assessments informed by cost." Identify those with the greatest benefit and least amount of risk/cost.	Identify the tactical and operational impacts Risk associated with technologies (tech, integration, schedule, manufacturing, cost) Assess COAs based on ECP eligibility, PM and user recommendations, attribute categories – workshop to evaluate COA and assess DOTMLPF impacts of each COA.	Power and energy Lethality Protection Survivability
8	IBCT/ABCT/SBCT CPR Support	TCM prioritization of solutions being proposed for inclusion in the POM and LIRA	Develop a feasible investment strategy; maximize capability gained over time.	Optimization model with an objective to maximize capability value subject to fiscal year budget, formation based gap/solution priorities, and logical constraints to include solution interdependencies.	Selection and timing of procuring specific solutions.
9	A2020 Tactical Wheeled Vehicle Strategy (2012)	Impacts of ARCIC proposed concept of TWV pooling.	Develop a framework to identify the choices that affect the acceptability of TWV pooling decisions in order to reduce overall TWV quantities.	A value focused thinking (VFT) approach leveraging the experience of a broad base of subject matter experts and stakeholders focusing on generating alternatives, with the following properties: Number of storage sites, Type of storage facility, and Maintenance staffing. Developed ROM cost estimates with SME. Applied benefit values to COAs.	Cost and Benefit
11	Army Reserve Capabilities-Based Prioritization Study (2008)	USAR, PA&E resource allocation	Build a reproducible, quantifiable, qualifiable and auditable methodology for the prioritization and allocation of finite resources.	Value Based Thinking model that prioritized capabilities / considerations of Army preferences, linking resources to capabilities/objectives facilitate determination of value, linking program value to available resources in order to develop a recommendation.	Resources Value

SECTION 3. SUMMARY

The product of this research project ended up being fairly different from the initial vision. I expected to be able to provide a greater level of detail for specific methodologies to consider. Even so, it is my sincere hope that this product will provide insight into the work that TRAC will continue to support.

3.1. RESEARCH

Trade space and associated analysis is a very broad and widely applied term. There is no limit to its application as a decision support methodology. Trade space analysis can span three dimensions: performance, capability, and value or utility. Systems Engineering reference to trade space analysis commonly refers to all three. It is highly dependent on the ability to quickly run numerous simulations to populate the performance or capability metrics associated with system design. In order to do this, simplified surrogate models or meta-models are commonly used. The same input parameters associated with a system's (technology or otherwise) performance inform both system performance and requisite capability measures. Many of the articles reviewed emphasized the role of the decision maker. The priorities and value systems of stakeholders and decision makers focus analysis towards the relationships amongst "tradeable" attributes that drive decisions. They also provide a way to collapse multiple dimensions – disparate performance and capability measures – to more easily communicate benefit (Ross & Hastings, The Trade Space Exploration Paradigm, 2005). One observation from this research was that there is a slight, but relevant, difference between trade space analysis and trade off analysis. Trade space analysis is the umbrella term. However, "tradeoff" analysis insinuates a certain level of "concrete-ness" of alternative definitions, attributes, and capabilities.

3.2. TRAC CASE STUDY

The TRAC studies included here commonly assess two of the three dimensions at a time. Cooperation across centers provides the greatest number of examples where all three dimensions are considered. Whether it is by design or happenstance based on the cases selected herein, capability and performance focused trades studies are more commonly WSMR led, whereas studies that incorporate value measures are either FLVN or LEE led.

3.3. ANALYST GUIDE

The guide covers trades related terms of reference[1], basic elements of trade space analysis and some associated challenges. It uses a simple example as a reference throughout; it is supplemented with examples from TRAC work. A survey of a few DoD examples of trades related decision support tools is included. See Appendix C for the guide outline.

[1] Interestingly, according to Wikipedia, the term tradespace has application as an organizational process management term; a collection of processes spanning multiple organizations. Potentially consider the application of this definition when looking at force design related studies: underpinning organizational changes, identifying efficiencies, etc. Note: this is the first page in Wikipedia that I have come across with multiple issues (e.g. too few references, no linking pages.)

SECTION 4. RECOMMENDATIONS

It took some time to define the scope of the trade space problem to address in this effort. There were a number of considerations that were not explored.

4.1. DATA VISUALIZATION

Based on some of the challenges identified, the importance of continual advancement in data visualization cannot be emphasized enough.

4.1.1 Decision Support Tools (Dashboards)

It would be of great benefit for TRAC to follow the NPS Systems Engineering department's work on illuminating trade spaces using metamodeling and interactive data dashboards.[2] This is not for passing off to a decision maker for them to use alone, but as an engine to guide discussions with decision makers and communicate analysis results. The primary levers within the dashboard are: design parameters, desired effectiveness measures, and physical constraints / synthesis measures. A potential use case might be the recently completed LRPF AoA since the analysis includes performance characteristics, specific mission task and desired operational effectiveness measures, and physical constraints. The range of potential values was of great interest. Being able to dynamically display the impact of changing the threshold requirement of a performance characteristic, to the effectiveness of a certain mission task, and the cost related to that change directly would be an innovation in how TRAC uses data visualization techniques to communicate with senior level decision makers.

4.1.2 Quality Function Deployment

Another opportunity to help facilitate the communication of our trades analyses is to employ a Quality Function Deployment (QFD)[3] like methodology. It is part of the Six Sigma "Define Phase." QFD is "a structured method in which customer requirements are translated into appropriate technical requirements for each stage of product development and production". "These tools are a series of tables and charts to then systematically disaggregate customer needs into prioritized product requirements, functions, technology, systems, subsystems, parts, reliability, cost, manufacturing, production, equipment setup, operator training and process controls" (Lean Process) QFD "is an extremely useful methodology to facilitate communication, planning, and decision making…". (Crow, Kenneth; DRM Associates) The following figure outlines the components of the basic model.

[2] There is not a published article. "A Systems Design Exploration Approach that Illuminates Tradespaces Using Simulation Metamodeling" is currently under draft. (MacCalman, Beery, & Paulo PhD, 2015)

[3] The DAU Acquisition Connection section 5.5.1 provides a brief overview of the model and its application.

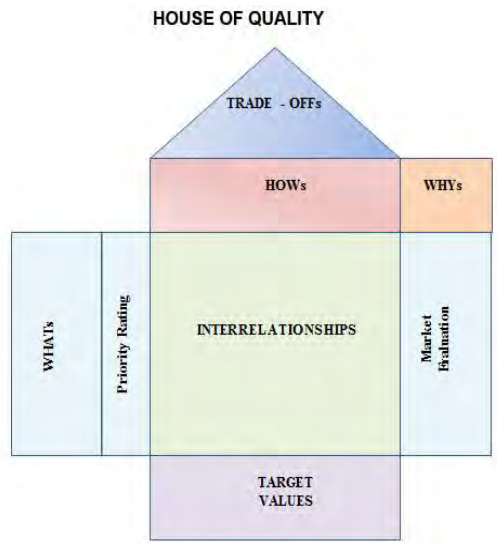

Figure 2: House of Quality (Defense Acquisition University)

The primary components are: defined capability requirements (*what*), prioritized rating of those capabilities, performance characteristics that enable capabilities (*how*), the codified interrelationships between the capabilities and performance characteristics along with the tradeoffs between performance characteristics, target values (performance, risk, etc.), and comparative areas for why the requirement exists. Just by definition of the various components, it contains all of the elements of a system requirement or capabilities based trade space analysis problem. Even though the QFD is primarily a qualitative tool, it provides a framework to quantitatively explore the relationships defined by the QFD. One example is the Relational Oriented Systems Analysis Engineering Technology Tradeoff Assessment (ROSETTA) Initiative by the Aerospace Systems Design Laboratory. This methodology uses qualitative SME data built as a QFD model with model and simulation data captured using response surface method (RSM) / response surface equations (RSEs) as surrogate models. It uses the RSEs with Monte Carlo simulation to quantitatively explore changes across the surfaces to develop greater understanding of the relationships represented in the QFD. (ROSETTA, 2015)

4.2. CONSIDERING DOTMLPF-P AND HUMAN DIMENSION (HD)

4.2.1 As a Concept

As the Army Operating Concept and TRADOC Commanding General Perkins suggests, we continuously focus on facilitating the Army's capabilities to achieve its objectives; that does not solely rely on technology or materiel solutions. Using this directive, perhaps TRAC's exploration of impacts of decisions at the widest level; consideration of the second and third order effects of decisions should consider an emphasis across elements in DOMTLPF-P spectrum.

> People are the critical elements within systems, so adopting a human-centric perspective of systems increases total system performance and minimizes total ownership costs. Optimization occurs in defense acquisitions, starting with the specification of system requirements and flowing down through system design, development, and deployment. (Tvaryanas, Lt Col USAF, MC, SFS, Brown, Col USAF, MC, SFS, & Miller (now Shattuck), PhD, 2009)

There are many overlapping elements between DOTMLPF-P and Human Systems Integration (HSI). For the Army, HSI domains include: manpower, personnel, training, human factors engineering which are referred to input or design domains while, survivability, health hazards, and system operation safety are outcome domains.

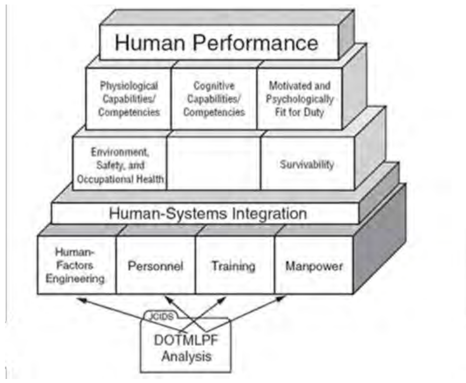

Figure 3: DOTMLPF-P Overlap with HSI Domains

In 2007, a NPS graduate student worked on developing a methodology for the DOTMLPF assessment of the Army's Land Warrior System, a TRAC-WSMR study. The work focused on the interrelationships between the DOTMLPF model and the domains of HSI. It also presented a survey methodology to collect DOTMLPF and HSI related data. (Alfred, 2007). With an ever increasing emphasis on Human Dimension (HD), it would be beneficial to include measures and metrics that capture HD related impacts on operational effectiveness during methodology development. Hopefully, the HD OR working group can leverage the relationship with NPS to do that.

4.2.2 Implications on Definitions

A nuanced shift in thinking of definitions associated with determining and assessing capability requirements could open up the aperture to non-materiel DOT_LPF solutions or alternative materiel solutions when a study explores capabilities and requirements. Consider the following definitions anchored in HSI principles[4]:

> People or groups have **capabilities** and **limitations**, physically or otherwise imposed (organization, training, leadership, policy), whereas, systems/tools (technologies) have **affordances** and **constraints**. A system *affords* the people or groups using it with capabilities. It is *constrained* by its functionality requirements (e.g. capacity of a clip or a gas tank, service life, maintenance cycles).
>
> Capabilities and limitations may change and system affordances and constraints may differ depending on varying conditions (operational environment, mission task, weather, etc.). The conditions that dictate requirements provide the **context.** The context matters when explaining the *"when"* and *"why"* of the capability requirement and the affordances that a tool provides.

[4] Adapted from discussions with Dr. Larry Shattuck, NPS OR Dept.

The *"why"* could reveal the range of tools that enable the required capability. The *"when"* could show the capabilities that are on or off the critical path to success thus affecting its tradability.[5]

Keeping these in mind could provide a framework for defining measures that assess: relevant impacts to trades and associated variables and describing alternative performance characteristics.

4.2.3 An Environment for Conducting Analysis[6]

The following is an ongoing ARCIC effort which may provide an opportunity to develop and test measures of effectiveness:

"Early Synthetic Prototyping is envisioned to provide a sandbox-like environment where engineers can rapidly model potential capabilities and concept developers can rapidly explore various concepts of operation. Soldiers are able play various scenarios specifically designed to elicit feedback to address research questions. Virtual game environments provide a robust capability that can support this objective. Virtual game environments provide a complex and engaging environment where various emerging capabilities can be assessed without significant engineering and/or prototyping efforts. Additionally, the game environment can be distributed to where the Soldiers are located and eliminates the need to transport Soldiers to centralized locations for limited duration experiments.

The focus of this effort is to answer the following problem statement: "How does the Army develop and implement a process and a set of tools that enables Soldiers to assess emerging technologies in a synthetic environment to provide relevant feedback to inform Science and Technology research and Doctrine, Organization and Training development?" Current materiel and concept development does not incorporate the operational experience of Soldiers before the materiel development decision point. This effort seeks to garner feedback from thousands of Soldiers of all ranks with operational experience to provide insights very early in the development timeline."

[5] Email discussion with Mr. Stephen Black from TRAC-FLVN.

[6] Excerpt from LTC Bill Platte Email Tue 14 April 2015

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APPENDIX ANALYST GUIDE